The Integration Of Computing Technology Into Undergraduate Mathematics Classes

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Abstract

This study investigated different calculus professors' conceptions about mathematics and mathematical learning, calculus teaching with or without the use of computing technology, and the experiences in which those conceptions were grounded. Six college professors were purposefully selected and studied. The results showed the professors' perceptions of the effects of technology use on pedagogy and students' learning; their perceptions of barriers and challenges to the adoption and use of technology for teaching and learning calculus; and their experience, knowledge, and motivation for adopting instructional technology that made unique and significant contributions to explaining faculty use of technology for teaching and learning calculus. Some professors were categorically opposed to the use of computing technology in calculus, but others envisioned that computing technology could play a multitude of roles in their calculus classrooms. The more that the calculus professors wanted to focus on real-world applications and wanted students to apply calculus concepts in their academic disciplines, the more they were concerned about their own ability to facilitate such learning and the need to integrate computing technology into calculus. The more that the calculus professors focused on procedural understanding in mathematics and on teacher-centered lessons, the more they were concerned about students misusing computing technology and failing to develop a proper understanding of calculus concepts.

Keywords: Computing Technology; Integration; Undergraduate Mathematics

1. Introduction.

Computing technology has come to be seen as providing potentially valuable tools for mathematics education reforms, not only at the elementary and secondary levels, but for higher education as well. Computing technology is important in undergraduate mathematics education because of its impact and influence on mathematical research, mathematical thinking, and mathematics teaching and learning. As a result, higher education mathematics faculties have been given greater access to innovative technology. Despite better access over the years, mathematics faculty members' utilization of computing technology has remained low. Although some have started using computing technology to teach in innovative and creative ways, most mathematics professors at higher education institutions make little use of computing technology as a tool for teaching (Biggs, 1999; Lim, 2000).

Research studies have shown that an instructor's conception of the importance of computing technology is a critical determining factor in the effectiveness of its implementation in the classroom (Groves & Zemel, 2000; Roblyer & Knezek, 2003; D. L. Rogers, 2000). In undergraduate mathematics education, mathematics instructors' understanding regarding how students learn and their personal conceptions of what constitutes positive instructional practices influence the way they use computing technologies in the classroom (Santucci, 2007; Simonsen & Dick, 1997). Any attempt to implement policy changes and adjustments, therefore, must be viewed in terms of the instructor, who ultimately controls how the technology will be used in the classroom. Without instructor involvement, all computing technology integration initiatives will fail. In order to achieve a successful integration of computing technology into classrooms, there is a need for a more complete understanding of the most constructive ways to promote change among mathematics instructors. According to Gadanidis, Kamran, and Liang (2004), the main barrier to the use of computing technology in the mathematics classroom is "the inability of American college mathematicians to recognize the value of such facilities and their unwillingness to make the effort to use the facilities which are available" (p. 279).

Despite the presence of an ever-increasing number of research findings, the efforts of dedicated collegiate mathematics instructors, and the growing access to technology, computing technology has not become an integral part of calculus classes. This study was conducted to understand why calculus instructors used or did not use computing technology in their calculus classes. To understand the why or why not, it was necessary to examine the ways in which instructors were using computing technology as well as their previous experiences with various types of technology. The goal was to understand why instructors did what they did—to describe and interpret how their conceptions informed and shaped the way that they choose to teach collegiate level calculus with or without calculus.

2. Institutions and Participant Selection.

The study was conducted in the mathematics departments of a large public research university and a large community college, both located in the southeastern United States. The site selection was based on previous research demonstrating how the institutional culture in higher education is shaped by the mission of the institutions (Beard & Hartley, 1987; Bogdan & Biklen, 2002; Burke, 2005; Cox, 2001). By employing two educational settings, the researcher tried to explore and compare the cultures of two mathematics departments, where ideologies, norms, and values are internalized through a socialization process (Braxton et al., 1996, Fairweather, 1996; Knapper, 1997). In addition, working with two institutions and selecting a broad range of information-rich participants aimed to address the aims of the study, as well as draw meaningful conclusions from the results.

To better understand the content, character, and expression of calculus instructors' conceptions of using or not using computing technology in teaching and learning calculus, the researcher chose a set of three calculus instructors from each institution for the study. The selection of the participants was purposeful and was partly based on their initial questionnaire responses. The goal of administering a voluntary initial questionnaire was to obtain initial information about the instructors' familiarity with the calculus reform movement, their comfort level with using computing technology, and their perception of the role of computing technology in the classroom. Among the three participants from each institution, the researcher choose one instructor who was using computing technology in calculus classes during the study, one who had never attempted to use computing technology, and one who had used computing technology in the past but was not using it currently. By selecting such individuals, the researcher aimed to discover similarities as well as differences in experience among the participants. The six calculus instructors were chosen because they were similar in some respects and dissimilar in others.

3. Data Collection and Analysis.

Understanding conceptions is very problematic because personal decisions and comments result from different causes. To study instructors' conceptions, an examination of their words alone is not enough—the examination should be supplemented with classroom observations and other data sources (Pajares, 1992; Thompson, 1992). In this study, the main sources of data were questionnaire responses, recorded interviews, field observation notes, and artifacts (e.g., calculus project handouts, instructors' curriculum vitae, examinations, and instructors' online communication postings). Each research participant was asked to participate in three semi-structured interviews that aimed to facilitate a participant-led discussion. The participants were asked questions regarding their previous experience in teaching calculus with computing technology, as well as what they perceived to be the ideal way to incorporate computing technology into the classroom.

The main goal of the data analysis was to extract the essence of the calculus instructors' conceptions of using or not using computing technology in teaching and learning calculus so that the essence could be used to communicate and to explore the meaning of those conceptions. The researcher looked across the data to identify the calculus instructors' conceptions through the constant comparative method. According to Bogdan and Biklen (2002), the constant comparative method "explores differences and similarities across incidents within the data currently collected and provides guidelines for collecting additional data" (p. 493). Thus, the data analysis process involved explicitly comparing each incident in the data with other incidents appearing to belong to the same category and exploring their similarities and differences.

4. The Analysis of Instructors' Conceptions of Mathematics and Learning Mathematics among Groups.

Several researchers pointed out the importance of conceptions of the nature and meaning of mathematics as a crucial part of the teacher's approach to mathematics teaching. Reuben Hersh (1997, p.13) noted "One's conception of what mathematics is affects one's conception of how it should be presented. One's manner of presenting it is an indication of what one believes to be most essential in it. The issue, then, is not, 'What is the best way to teach?' But, 'What is mathematics really about'?" This study finding confirmed Hersh's claim that the conceptions of the faculty members had a strong influence on their methods for teaching calculus. This influence was evident in the decisions and techniques implemented in the classrooms, and the conceptions varied across the three groups.

Adopting Ernest's (1989) categorization of an individual's mathematical philosophy, the mathematical conceptions of the professors who were using technology were most aligned with the problem solver category: Mathematics is a continually expanding field of human creation and invention. The data analysis further aligned the professors' categorization through Rokeach's (1968) three components of a conception: the professors' cognitive, affective and behavioral dimensions of his or her conceptions of teaching mathematics. The cognitive component of the professors' conceptions was their view that the subject was a quasi-empirical science, and they believed that performing mathematical research and teaching mathematics involved carrying out a substantial amount of experimental work before coming up with useful generalizations. The affective component of the conception was defined by the fact that the professors were actively engaged with their students, focusing on what the students were learning, and were responsive to their students' needs. They had a strong connection with their students and viewed them as individuals. The professors wanted to challenge each student as an individual rather than just the class as a whole. The behavioral component of the conceptions was defined by the perception of performing mathematics through carrying out laborious, deliberate experimental work. They saw learning mathematics as a process of inquiry and coming to know oneself, and defined their role of instructor as a facilitator whose goal was to ensure that their students would become confident in their ability to pose and solve problems.

The conceptions of the faculty members that had used computing technology in the past and decided not to use it anymore aligned most with Ernest's (1989) instrumentalist view of mathematics; they saw learning mathematics partly as an accumulation of facts, rules, and skills in the pursuit of understanding mathematical concepts. In regards to Rokeach's (1968) three components of a conception, the cognitive component of the professors' conception was their view of learning mathematics as hierarchical and as a process of making connections between new and previously learned ideas. The affective component of their conception was their view that incorporating technology into the classroom had proven to be too time-consuming and troublesome. In addition, they viewed their students as too intellectually immature to use technology responsibly. The behavioral component of their conception was that they taught mathematics to help students achieve a mastery of designated skills and a level of mathematical understanding.

The faculty members who never used technology in the classroom were most aligned with Ernest's (1989) platonist view: mathematics is a unified body of certain knowledge. The cognitive component of Rokeach's (1968) definition of conception in regards to these professors was the thought that mathematical knowledge was pure and timeless, and that it had universal validity. They liked the subject because it was very logical and required precise thinking, and were motivated by intellectual curiosity and a desire to know the truth. The affective component of their conceptions was defined through their belief that the study of mathematics is beautiful and pure. These professors saw mathematics primarily as an elegant intellectual achievement and an analytical tool that represents the world in symbolic forms, and as a hierarchical subject that builds upon what one has already learned. The behavioral component of their conceptions was demonstrated through their attitudes of performing proofs and exercises as the best way to learn mathematics, and they thought teaching mathematics was mainly about teaching students to think clearly and logically. For them, the role of the students was to learn the fundamentals, and each one of their students needed to be equally willing and prepared to learn the fundamentals of mathematics. These instructors equated the aptitude of performing mathematics and developing their skills to the talent and patience of artists or musicians: you either have it or you do not (King, 1992; Poincaré, 1910). Because they considered mathematics as a timeless and pure science, they believed that technology only got in the way of an already perfected strategy of learning mathematics. They believed that students' algebraic preparedness was necessary for learning calculus, and poor performance was indicative of a lack of knowledge, preparedness, or willingness to succeed in the field. Thus, they treated the student body as a whole, rather than focusing on the individual.

Seeing themselves as explorers of mathematics, these professors loved the challenge of understanding abstract concepts, and saw the practice of mathematics as a form of self-growth. Though the professors did believe that to some extent the real-world application of mathematics was also important, they described mathematics primarily as a way of thinking. They said that developing fluency with symbolic manipulation and basic skills was necessary since students needed to have those skills to communicate and learn more advanced concepts. According to these professors, mathematics was essentially an abstract subject, and it should be taught as a set of concepts, skills, and calculations. They emphasized developing students' reasoning abilities, which they defined as a line of thought and a way of logical thinking, adapted to producing assertions and reaching mathematical conclusions. They saw mathematical reasoning as objective and rigorous, and believed students should be able to use their own logic without the use of technology for reflection, explanation, and justification.

5. Why do They Use Computing Technology? And How do They Use Computing Technology?

The professors who were using technology saw that the transition towards the use of technology would open up new ways to explore mathematics (Grassl & Mingus, 2007; Norton, McRobbie, & Cooper, 2000), in the same way that a microscope allowed biologists to explore life on a molecular level. Because they believed problem solving and trial and error were the best way to learn mathematics, they used technology to help students learn in that style. Fascinated by the connections between mathematics and other disciplines, they wanted their students to realize that mathematics really does make sense, and encouraged the students to perform in the classroom as mathematicians would through mathematical explorations. The professors were primarily focused on the interplay between seeing mathematics as a set of skills and procedures and finding value by applying it to the real world. Because they viewed mathematics as a subject that could be implemented in other subjects as well as a tool to use in real-life problem solving, they concluded that technology could be used to strengthen problem-solving skills.

Like Ely (1999), the professors had been dissatisfied with the status quo, feeling a need to change. That dissatisfaction had motivated them to adopt and use computing technology for teaching and learning calculus. They believed that the use of computing technology allowed them to show connections between mathematics and other academic disciplines through real-world problems. They believed that learning mathematics required that students see and learn the application of calculus concepts and ideas in context. Their problem solver conception of mathematics made them realize that solving real-world problems from different academic disciplines could serve an important tool for getting students to be active in their calculus learning. They also saw that the use of computing technology allowed the students to take more initiative and become more independent in their calculus learning. In their experience, the use of the computing technology increased the students' motivation and engagement.

The professors had extensive experience with the available tools, and knowledge about the way they work. Because they were experienced with the tools, they believed strongly that the introduction of computers had provided new and powerful tools for doing mathematics. It helped mathematicians make new mathematical discoveries and develop new conjectures, and the application of applied mathematics methods had widened the scope and dimensions of mathematical research. These professors saw technology as an integral part of their students' lives, and they were aware of the fact that many of their students had used different computing technological tools before they came to college. Overall, the professors' journey towards integration of computing technology into calculus supported McCracken's (2008) findings that faculty would experiment with technology integration if they felt the integration of the computing technology was consistent with their teaching style and conceptions of mathematics. These professors thought their students were knowledgeable and competently skilled, and they could see how it was pedagogically useful in students' learning of calculus. They saw that the nature of the technology design largely determined the impact of integration efforts on student achievement, and ongoing formative evaluations were necessary for continued improvements in technology integration.

These professors saw teaching as an opportunity for continual learning and growth; they constantly reflected on what they were doing and sought new ways to improve their teaching through revision of class activities and their choice of computing technology tools as well as the ways they used these tools in teaching and learning calculus. They believed that technology could, and should, be used to facilitate mathematical understanding and thus could be used profitably at most any stage of the calculus learning process as supported by several previous research findings (Heid, 2002; Judson, 2007). The professors could help their students to develop an intuitive understanding of calculus by using multiple representations of the concepts through the use of computing technology. They believed strongly that technology should be constantly available to their students; the availability was intended to provide a variety of choices to both instructor and student. Because the faculty members felt a strong connection with their students, they decided to implement technology to better convey information in a form of learning that they thought the students were more accustomed to, as well as providing a means of better connection and relationship between the instructor and the student. The professors believed that the process of learning mathematics required problem solving and learning from mistakes, and they consistently implemented technology as learning tools in order to help better understand and teach the material.

As implied by Hamrick, Schuh, and Shelley (2004), the professors saw various opportunities to implement technology in the classroom and decided to capitalize on it in their instruction of calculus. From their perspective on teaching, these professors saw students as partners in the learning process, and they tried to develop a positive rapport with students by being sensitive to their aims for taking their classes as well as helping them to fill their knowledge gaps in algebra and precalculus concepts. They tried to accomplish that aim by providing certain Web page links for reviewing these concepts, by encouraging students to come to them during office hours, and by paying special attention to students' questions by not dismissing any information or a particular step in algebraic simplification. They used technology for various purposes including communicating with their students, making class notes available online for them to review later, motivating them to learn concepts, and showing the applications of those concepts in various academic disciplines. The professors took opportunities to demonstrate the ways that technology could be used by finding the function of a line tangent to the function f(x) at point X, the average rate of change of a function, the mean value theorem, Rolle 's Theorem, and using the secant method for solving equations. They used various computing technologies for in-class demonstrations and students' explorations in order to help them develop an intuition for calculus concepts and processes. These professors tried to graph functions and their derivatives simultaneously to help their students see the intuitive connection between a function and its derivative. They also used technology to help students visualize abstract concepts and provide a dynamic representation of the idea of convergence, such as showing how the secant line becomes a tangent line as Δx goes to zero. These instructors saw the opportunities that technology had to offer, and took full advantage of it in their instruction. They used the zoom feature of a calculator to narrow in on a graph so that students could understand the concept of local linearity when learning about the derivative and linear approximations. They constantly searched for creative ways to integrate technology such as using it to plot a Valentine's Day card by graphing polar equations and using Newton's method to find solutions to equations that were derived from mathematical models in problems from different disciplines. In that environment, the faculty members could turn to technology whenever they deemed it valuable or appropriate. Similarly, during certain classroom activities, students were given the option of using technology or not, and the professors were adamant that their students be allowed to use computing technology in all situations.

6. For Instructors Who Never Used Computing Technology to Teach Calculus: Why do They not Use Computing Technology? And How do They Teach Calculus Without Using Computing Technology?

Because they viewed mathematics as a pure science and theory, these professors concluded that technology would be of no use to their calculus teaching. They were mainly concerned with helping students to develop a conceptual understanding of calculus concepts and believed that the presence of computing technology prevented them from achieving that goal. This finding was in line with E. M. Rogers's (1995) theory of relative advantage. Rogers argued that even if individuals are exposed to innovation messages, such exposure will have little effect unless the innovation provides some advantage over the traditional ways of doing things. Furthermore, McAlpine and Gandell (2003) argued that even if individuals were exposed to innovation messages, such exposure would have little effect unless the innovation was perceived as relevant to the individual's needs and consistent with the individual's attitudes and beliefs.

A key reason that the professors chose not to implement technology was that they had limited knowledge about computing technology tools. They knew how to use some computer software to do mathematical investigations and for graphing, but they had very limited knowledge about using graphing calculators and were not knowledgeable about the existence of various Java applets or Web pages to conduct mathematical explorations or demonstrations of calculus concepts. These professors further believed that the early introduction to, and extensive use of, calculators had hindered their students' development of number sense and algebraic skills. They thought it was unacceptable for students to be unable to perform basic arithmetic and symbolic manipulation by hand. By not letting their students use computing technology in their calculus classes, these professors intended to force the students to develop those skills. They thought students should have mastered fundamental skills and concepts before they started to use computing technology for learning mathematics. Although they were categorically opposed to using computing technology in first- and second-semester calculus, these faculty members were open to its use in upper level mathematics courses. As demonstrated by the findings of LaBerge, Zollman, and Sons (1997), some mathematicians believed that students were not sufficiently knowledgeable about the subject to utilize the use of computing technology in calculus instruction. These professors believed that progressive knowledge development was the key to long-term progress in mathematics and, with their emphasis on proofs and deriving the relationships, they believed that they were helping students to gain a solid grasp of basic knowledge and techniques. The professors' insistence that the students needed to be better prepared before entering the calculus classroom shaped their decision to not use technology, as that would be using a method that was unnecessary for learning.

Adamant that the use of technology was unnecessary, and perhaps even detrimental to a student's learning of calculus, these professors chose to teach using more traditional methods. They emphasized exploring mathematics through its concepts, and doing mathematical proofs served that purpose most efficiently. They were most concerned with helping students to develop a conceptual understanding of mathematical knowledge through doing mathematical proofs and asking students to provide logical arguments. As Hersh (1997) explained, a professor presented mathematics in the same way they understood mathematics. These professors were interested in sharing what they found beautiful in doing mathematics, believed that calculus should be taught more traditionally, and decided that technology would get in the way. Their instruction was focused on providing mathematical proofs and logical deductions. In their classes, they regularly presented mathematical proofs of calculus concepts including the chain rule, the mean value theorem, and the fundamental theorem of calculus. During their demonstration of proofs, they tried to engage the students by asking questions. When a student asked a question during class, they generally tried to answer it with more questions, believing that this process allowed them to gauge each student's current mathematical conceptual framework. They were also quite adamant about showing the derivation of mathematical concepts and ideas from previous ones. In their classes, they constantly showed the derivation of trigonometric identities when their use was required in solving problems to demonstrate how mathematical ideas were related. Their aim was to convince students that while working on problems in the classroom and on exams, the solutions should be fully simplified at the end. They insisted that students should have known the unit circle values, and they chose classroom exercises and examination questions so that the result would exactly correspond to reference angles.

Their teaching can be summarized as starting with the delivery of the lecture by presenting relevant ideas and theories and hoping that their lecture and the use of concrete examples would help students to digest the concepts and ideas. They also assigned enough exercises when they believed that a successful competition of assigned problems would help students to develop fluency with related skills and get ready to wrestle with more abstract concepts. They saw that examinations and assignments were ways to help students understand their progress in learning calculus and helped to self-evaluate their teaching. If they saw a pattern of misunderstanding or observe logical deficits of their students, they tried to remedy the issues through their lectures.

7. For Instructors Who Once Used Computing Technology: Why do They no Longer Use Computing Technology? And How do They Teach Calculus Without Using Computing Technology?

The professors who had abandoned the use of technology in the classroom were very similar to those who had never used it. They believed that the instructor's role was to deliver the content by giving appropriate lectures. They believed that their students were not intellectually mature and were perpetually in a state of learning. As a result, they adopted a belief in line with Quinlan's (2007) study demonstrating that a majority of mathematics professors believed that the use of the computing technology was better suited to teaching rather than learning. They wanted their students to understand the importance of the reasoning behind the problem, and they believed that the job of the students was to observe and absorb. Furthermore, they had the view that the students were not intellectually mature enough to learn to use computing technology to further their mathematical understanding. This conception was supported by LaBergeet al. (1997), who demonstrated that some mathematics faculty members believed that some of their students were not ready for implementing the pedagogical techniques that required more initiative for the students to perform independent explorations. Although they might have liked to include activities involving the use of computing technology to help the students to learn mathematics, these professors believed that many of the students were not prepared by their previous education experience to participate in such activities. These professors observed that their students would often use technology without a defined or purposeful strategy, thus resulting in an overreliance on the technology (Doerr & Zangor, 2000; Forster & Taylor, 2006). Like those who never used technology, these professors focused more on the class as a whole rather than on the individual students in it.

The professors thought that the main goal of teaching mathematics was to help students achieve mastery of designated skills and a level of mathematical understanding. They claimed the use of a graphing calculator hindered the students' ability to read and interpret the graph, and some students' inability to see the first derivative as a function made it harder to understand the relationship between the first and second derivatives. They said that they had initially envisioned the beneficial effects of technology on instruction and students' learning as issues that had motivated them to adopt and use technology to help students develop a deeper understanding of calculus concepts. However, after their attempts at integrating technology into the classroom, they developed misgivings about the use of computing technology and decided that it was not helping their students develop a better understanding of calculus concepts. On the contrary, these professors felt that the use of technology had hindered the students' mastery of fundamental algebraic, arithmetic, and calculus skills. They wanted to help students acquire mathematical habits of mind, and they believed the use of computing technology hindered that process because it replaced students' mathematical understanding.

These professors had experience with the tools they wanted to use but thought the time spent on teaching students how to use computing technology to conduct mathematical investigations was not worth it, because it took away time they could use teaching them fundamental skills and concepts. Furthermore, they claimed that the majority of their students were already anxious about learning the abstract concepts of calculus, and requiring the use of computing technology for calculus investigations would create extra pressure on those already anxious students. During the time these professors were using technology in the classroom, they observed that some of the students would become confused and spend more time working on the issues with the computing technology rather than on using it to make progress in their mathematical understanding, as noted by Graham and Thomas (2000).

After their technology integration attempts, these professors came to believe that their students lacked the maturity to use computing technology to conduct mathematical explorations, and they did not want their students to develop an overreliance on the calculator. This perception made them consider continuing to use technology to teach calculus concepts while not allowing their students to use technology to work through the problems. Ultimately, these professors became convinced that students should not be allowed to use technology tools in their learning because their use prevented the students from developing basic skills and understanding. They noted that the use of computing technology in learning calculus without having achieved a mastery of basic concepts and skills caused students to develop a false sense of confidence in their ability to perform mathematics.

Although these professors had implemented technology at one point in their teaching careers, they eventually realized that the use of technology was a poor substitute for time-tested teaching methods. At the time of data collection, these professors were teaching in much the same way as those who had never used technology in calculus instruction, utilizing a much more traditional method. They delivered the lecture, presented the ideas and theories, and tried to use concrete examples. They thought that when the instructor gave examples, they could capture students' attention and make it easier for them to remember a conceptual element. In their teaching, these professors structured the subject matter in such a way that students had to see each detail as a part of an integrated whole. The students' roles were reactive; that is, they were asked to internalize patterns of thought explained to them by the instructor, and then to make those thought patterns a part of their own mathematical knowledge. In class, these professors worked examples similar to those they assigned for homework. They believed grading had to give points to students who had demonstrated an attempt to improve their ability to perform mathematics, and they allowed the students to resubmit the assignments.

These professors insisted that students should have learned calculus ideas and concepts with paper and pencil first, and that faculty should not use technology until after the students already knew how to do the mathematics by hand. They believed that students needed to have a solid understanding of fundamental mathematical concepts, and that technology could be used to enhance that understanding later. This conception was illustrated well through their conceptions about students' learning of graphing and the limit concept. They wanted their students to know how to graph and find limits of functions by hand. The professors thought the role of technology in calculus instruction should always be supplementary; it was important to them that the technology not be constantly available to the students, and they did not want technology to be perceived as the primary source of instruction. Furthermore, they were convinced that students should not have used technology before they had mastered basic skills and knowledge, in the same way that a student driver is allowed behind the wheel of a car only after passing a written exam demonstrating that he or she had the required basic knowledge of traffic rules.

8. How do Instructors in Community Colleges and Universities Differ in Their Teaching of Calculus With or Without Computing Technology?

Among the three groups examined, their conceptions shaped the decision of whether or not to implement technology in the classroom, and helped define the methods each used to teach calculus. These decisions in the classroom were further defined depending upon whether the calculus class was offered at a large university or a smaller community college. As an open-access institution, community colleges provided educational opportunities to a wide spectrum of students, including providing educational opportunities for traditionally low achievers (Bowen, Chingos, & McPherson, 2009; Burke, 2005). The faculty all agreed that many students did not possess sufficient knowledge or skills involving algebraic concepts, and said that a lack of algebraic readiness would be a significant barrier to succeeding in calculus. However, some instructors also noted that previous mastery of algebraic concepts was not the only indicator of potential success in learning calculus, as a student's desire to learn would also affect their ability to be successful in calculus. Certain restrictions between the two types of institutions shaped the decision of whether or not, as well as how, to use technology in the classroom. Compared with the university, the community college had much less freedom and more restrictions regarding the use of certain computing technologies and assignment techniques. The university professors had fewer restrictions and could teach as they pleased, but certain restrictions in the community college, such as the department's policy of prohibiting the use of the TI-89 graphing calculator and the TI-Inspire, hindered at least one instructor's decisions. That instructor did not believe that the use of advanced calculators interfered with her students' abilities to learn calculus concepts, and could in fact strengthen their understanding of more difficult concepts, but she was forced to comply with the department policies. With the use of superior calculators, instead of focusing on symbolic manipulation, students could pull away from the more concrete aspects and stick to the more abstract theoretical concepts of calculus. In addition to certain technological restrictions, the instructor was also required to conduct an in-class exam, when she would have preferred to assign a project to the students using real-world applications. When working in an open access institution like a community college, some faculty members also thought that it was necessary to make changes in their instructional methods. For example, one faculty member felt obligated to teach students how to use an instructional program, Maple, to better prepare those who would chose to move on to larger institutions that made use of the program.

Faculty members at both institutions were in favor of offering different sections of calculus to help overcome certain difficulties. They all agreed that the current generic calculus classes were difficult to teach because they were required to accommodate numerous students' needs, which varied in terms of their mathematical background, skills, personal experiences, and the expectations of their academic disciplines. They all also complained about the difficulty of finding class activities and problems that were relevant to students' academic disciplines, as many were not primarily focused on mathematics. The professors also felt the pressure of implementing a differentiated calculus instruction that was responsive to students' needs and expectations, and they observed that current traditional calculus classes did not really serve the needs of students. Although some faculty members were categorically opposed to the idea of integrating computing technology into their current generic calculus classes, they were open to the idea of exploring the educational opportunities involved in integrating computing technology into the other sections of calculus. However, one professor in the university was concerned with the possibility of offering different sections of calculus based on the student population without sacrificing the rigor of these calculus sections.

In summary, the contextual conditions in their teaching environments appeared to have some impact on professors' technology integration decisions. This finding is supported by the assertions of Surry and Ely (2006), which stated that the process of technology integration was consistent with the policies and missions of a given institution. The faculty members' conceptions of mathematics, their conceptions of learning mathematics, and their attitudes and beliefs towards technology were the primary agents when they made decisions about the integration of computing technology into their calculus teaching regarding activities and lecture structure (Hamrick et al., 2004; Hersh, 1997). The professors' concerns about teaching with technology could be categorized into two main areas: instructor responsibility and student responsibility. The more a professor wanted to focus on conceptual understanding and wanted students to take responsibility for that understanding, the more the professor was concerned about his or her own instructional techniques to facilitate such learning and the need for the availability of computing technology. The more a professor focused on procedural understanding in calculus and on teacher-centered lessons, the more he or she was concerned with students misusing the computing technology and failing to learn fundamental skills, concepts, and procedures. The most important issues found among professors in this study were the expectations of success and the perceived value of differentiating levels of computing technology usage. The professors who were users of technology tended to have more positive attitudes about technology integration, to have higher motivation for using technology, and to have more positive perceptions of the effects of technology on students' learning of calculus. They were more knowledgeable about the pedagogical opportunities and constraints of a wide range of different technological tools. Furthermore, they had a deeper understanding of the manner in which the subject matter could be presented, and they types of representations that could be constructed and changed by the integration of computing technology. The faculty members' conceptions of mathematics also appeared to have a strong influence on the methods they used to teach calculus. This influence was evident in the faculty members' educational decisions and the techniques they implemented in their classrooms. The impact that their conceptions of mathematics had on their teaching was comparable to a chef's conception of a good meal; the ingredients he or she chooses, along with the amount and type of seasoning and the cooking technique he or she uses will all contribute to the creation of a fine meal.

9. Conclusions and Implications

This study revealed that some instructors were not aware of the various roles that technology could play in teaching and learning calculus. Although previous research studies of undergraduate mathematics education provided abundant evidence and possible opportunities, the calculus professors were not aware of the existence of those studies. There is a strong need for sharing these research findings with the faculty through professional development opportunities. The faculty need to see that technology can play important roles in teaching and learning calculus to become convinced that the use of computing technology could motivate students and help the students' development of procedural and conceptual understanding of calculus.

In this study, while all faculty members were aware of the procedural roles that computing technology could play, some were not aware of the conceptual roles that it could also play in calculus instruction. These conceptual roles include demonstrations, illustrations, visualizations, and explorations, as well as making connections to other mathematics as well as to the real world. The professors needed opportunities to see that the use of computing technology could serve as a medium through which the students would come to understand a mathematical concept. They also needed opportunities to see how its use could help illustrate mathematical concepts that might otherwise seem extremely abstract so that they could start developing appreciation for the power technology has for allowing students to visualize mathematics—to see things that they might not otherwise see.

Furthermore, the students' success stories should be presented to convince the faculty of how technology might help students get beyond procedures and see the big picture. In this study, some faculty members also expressed their concerns regarding the existence of technology and students' basic skill development and their understanding of basic concepts. Several mathematics education research studies with undergraduates demonstrated that the integration of computing technology did not interfere with students' basic skill development and could have been introduced (Heid, 1988; Hillel, 1993), and the presentation of these studies in tandem with students' success stories and activities might challenge some faculty members' perception of learning mathematics as a hierarchical process. In this study, some faculty members also expressed their willingness to try to integrating technology into their calculus classes if they were not teaching the generic version of calculus, which made it difficult to integrate computing technology and still be responsive to different students' needs. There is a need for mathematics departments to explore further the feasibility of offering different sections of calculus for different clientele. Furthermore, the department should also search for opportunities for the input of different academic departments regarding their expectations from calculus classes and search for opportunities to make their calculus curriculum more responsive to their needs and expectations.

The successful integration of computing technology into calculus classes requires having a clear departmental vision of the computing technology integration and the expectations from the faculty to implement such a vision. Creation of such a vision requires getting the faculty members' input, addressing their concerns, and communicating the departmental expectations clearly regarding its implementation. In this vision, the need for aligning the classroom practices with the use of computing technology and the technical support for the faculty, as well as the department commitment to help professors gain the necessary technological knowledge and expertise to integrate technology into calculus classes, should be addressed. In this study, some faculty members said that such a vision and commitment on the part of academic administrators in terms of firm and visible evidence of continuing endorsement and support for technology integration seemed to be lacking or at best half-heartedly practiced. One of the ways to motivate calculus faculty members to integrate computing technology into their calculus classes would be to require technological skills and use in teaching as part of faculty evaluation. If faculty members are aware that the use of technology in their instruction is part of their evaluation for tenure, they might view the implementation of technology more seriously and invest the time and effort needed to take the initiative towards integration. That policy would call for the integration of technology into the curriculum and instruction and at the same time would make sure the contextual conditions for the implementation of educational innovations are in place. Mathematics departments might also consider the setting up of educational technology standards to guide faculty in their technology integration activities.

Although this study implied that successful technology integration had proven benefits, some professors still had some misgivings about its implementation. These instructors believed that technology would essentially perform the work of students for them, and not allow them to grow intellectually as mathematicians. Additionally, because a strong fluency in the use of technological tools was necessary for successful implementation, too much time would be spent learning to use these tools rather than learning mathematical concepts. The professors who shared these misgivings seemed to have a time-tested method of teaching calculus concepts, and the inclusion of technology in institutional policies would affect their ability to teach in the methods that they were accustomed to. They had their own teaching methodology, and it had been proven successful in their eyes—and their methodology may have been successful. Because some never used technology in the classroom before, their understanding of available tools was limited. There was a steep learning curve for some software packages. The research and investment necessary to understand and integrate computing technology in calculus would be time consuming. These professors saw that the integration of technology could negatively affect their opportunities for rewards through promotion or chances for tenure, or perhaps they did not see the future of technology. The integration of computing technology policies should be effectively communicated to them, and they should be given enough support to make a smooth transition, through demonstrating its value and supporting it with evidence of its benefits.

Adopting computing technology successfully involves more than the instructor's ability to use it as a tool; successful adoption requires changing the pedagogical practices of instructors (Park, 1996; Rogers, 1995). The integration process itself reveals and embodies what some instructors of calculus want to emphasize or avoid. Instructors are compelled to examine their feelings about technology as a legitimate means to an end by considering questions such as: What do students really need to learn? And have paper-and-pencil skills remained relevant in today's world?

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